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FULL-GLACIAL SHORELINE VEGETATION DURING THE MAXIMUM HIGHSTAND AT OWENS LAKE, CALIFORNIA

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ABSTRACT.—Owens Valley, California, was markedly different during the Wisconsin glacial stage from what it is today. Alpine glaciers bounded the Sierra Nevada, and pluvial Owens Lake reached highstands and overflowed its natural basin. We analyzed three layers from two packrat middens, dated to ca 23,000–14,500 yr BP, obtained from Haystack Mountain (1155 m) only 10 m above and <100 m from the highstand strandline of pluvial Owens Lake. During this period vegetation near Owens Lake reflects the influence of the Tioga glacial advance and retreat on lake levels, and microclimatic effects on shoreline vegetation. Between ca 23,000 and 17,500 yr BP a Utah juniper (*Juniperus osteosperma*) and single-needle pinyon pine (*Pinus monophylla*) woodland existed at the site. In the layers dated to ca 17,500 and 16,000 yr BP, macrofossils document the presence of Rocky Mountain juniper (*Juniperus scopulorum*), a species that no longer occurs in California. It is suggested that meltwater from the retreating glacial ice inundated the Owens River Lake chain causing pluvial Owens Lake to reach its highstand. This caused an increase in effective moisture, due to high groundwater, allowing the mesophytic Rocky Mountain juniper to exist at the site.

Key words: paleoecology, packrat middens, Rocky Mountain juniper, Juniperus scopulorum, *pluvial Owens Lake, Tioga glacial stage, California.*

Few places in western North America record such a full range of Quaternary events as found in the Owens Valley of eastern California. Within the confines of the narrow Owens River corridor, never more than 33 km wide, is found evidence of late-Quaternary glacier expansions (Birkeland and Burke 1988, Bursik and Gillespie 1993), volcanic eruptions (Pakiser et al. 1964), and expansion and contraction of large "pluvial" lakes (Lajoie 1968, Smith and Street-Perrott 1983, Benson et al. 1990). Such deposits are the manifestations of great climatic and environmental changes that have occurred during the late Quaternary.

Less studied but equally striking is the record of biological changes contemporaneous and associated with pervasive changes in the physical system. Pollen from pluvial lake sediments (Leopold 1967, Batchelder 1970, Davis unpublished) has been used to reconstruct the broadscale, regional changes in vegetation. Other studies (Koehler and Anderson 1990, Jennings and Elliott-Fisk 1993, Koehler unpublished) have relied on packrat (*Neotoma*) middens, which record local vegetation changes. A combination of all proxy indicators will ultimately allow a comprehensive picture of environmental change to be revealed.

The goal of this study was to investigate the pleni- to late-glacial vegetation communities near pluvial Owens Lake (Fig. 1), which fluctuated considerably during this period. Increased effective moisture and glacial runoff during the late Wisconsin initiated a series of overflow events in the lakes that define the Owens River system (Fig. 1). The chain began in the Mono Lake Basin where Pleistocene Lake Russell (Putnam 1950) overflowed when it filled to 2175 m elevation (Lajoie 1968, Benson et al. 1990). Owens River then flowed through the Adobe Valley and mixed with waters from Long Valley en route to Owens Lake. Owens Lake periodically filled and overflowed at 1145 m. Eventually, runoff flowed to China and Searles lakes, then into Lake Manly in Death Valley (Smith and Street-Perrott 1983). Lake levels fluctuated considerably between ca 24,000 and 21,000 yr BP, followed by high and relatively stable lake levels between 21,000 and 14,000 yr BP (Smith and Street-Perrott 1983).

Six layers from two packrat middens found at 1155 m elevation in Owens Valley, Inyo County, California (Fig. 1), document full-glacial vegetation changes during the period between ca 23,000 and 14,500 yr BP. The

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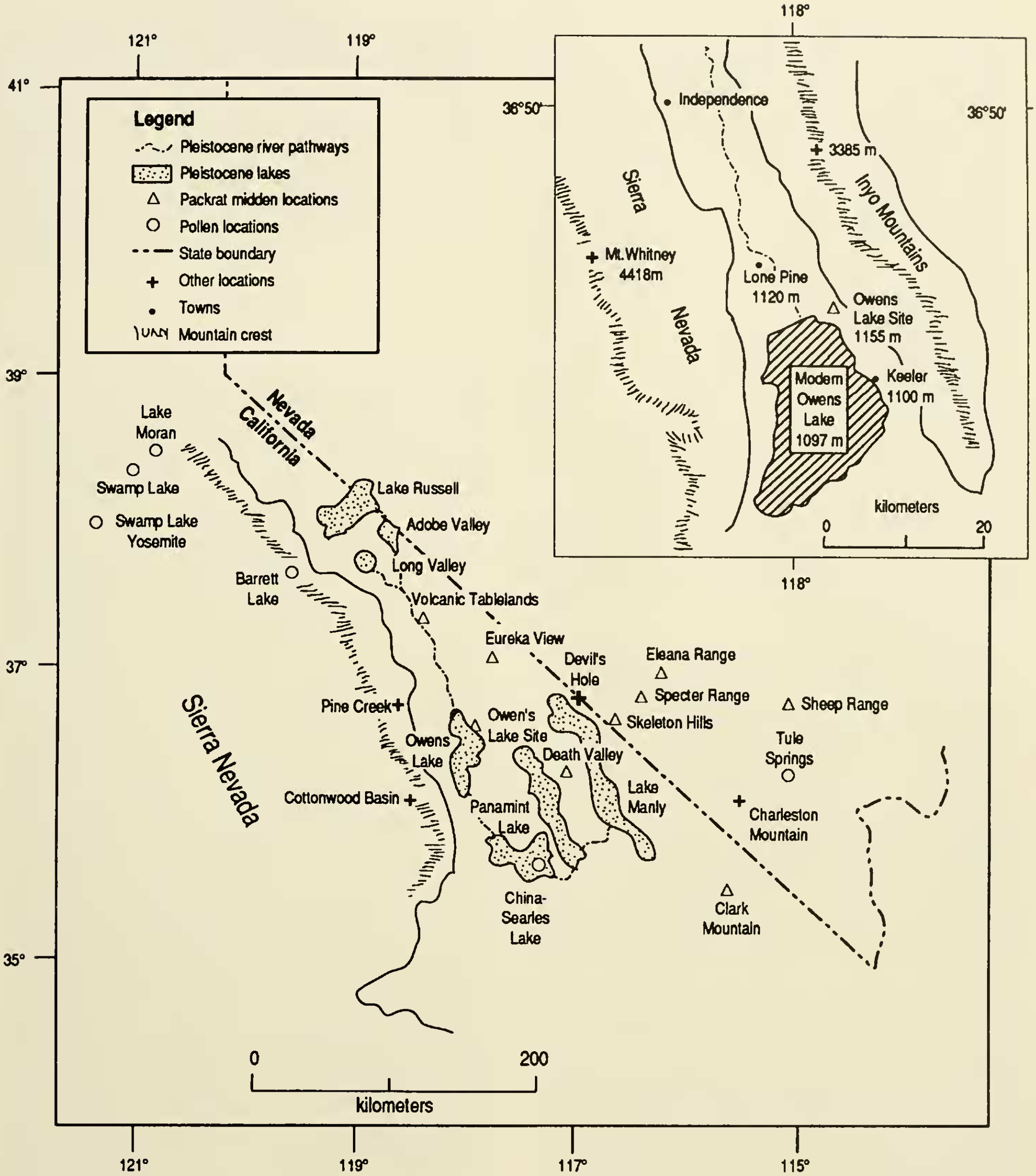

Fig. 1. Map showing the Owens Lake chain and sites discussed in the text (map is after Smith and Street-Perrott 1983).

midden assemblages described here are important in deducing paleoenvironments of the region for several reasons. First, the middens occur within 10 m elevation of and <100 m away from the pluvial Owens Lake maximum highstand strandline. Second, the occurrence within several middens of plant macrofossils of Rocky Mountain juniper (*Juniperus scopulorum*), a tree not found today in California, suggests that pluvial highstands during glacial retreats produced a unique microclimate at this nearshore location.

THE SITE

Owens Valley lies between the massive Sierra Nevada to the west and the Inyo-White Mountain ranges to the east. The Sierra Nevada rise from California's Great Valley, with a gentle westward gradient of 6% toward a lofty crest that contains some 500 summits over 3660 m, with 11 peaks over 4260 m. The eastern escarpment of the Sierra plummets, with a ca 14% gradient, as much as 3050 m into the Owens Valley. The graben forming Owens Valley ranges ca 13–33 km wide, with an average elevation of only 1160 m. The eastern flank of the Owens Valley is bounded by the Inyo-White Mountain chain, with a crest elevation that averages ca 2900 m.

Two indurated packrat middens, containing six stratigraphic units, were found at a single location on Haystack Mountain, ca 3 km east of the Inyo Mountains (36°36′N, 118°05′W; Fig. 1). The outcrop where the middens were found is of a spheroidally weathered Cretaceous granite (Ross 1967) and faces southeast. At 1155 m the site is located ca 100 m north and 10 m above the Owens Lake highstand strandline (1145 m).

Currently the local vegetation is dominated by a saltbush (*Atriplex* spp.)/hopsage (*Grayia spinosa*)/sagebrush (*Artemisia* spp.) community on the valley floor, while wolfberry (*Lycium andersonii*), mallow (*Sphaeralcea* spp.), and various species of the grass family occupy the immediate rock outcrop. Creosote bush (*Larrea tridentata*) and bursage (*Ambrosia dumosa*) are found locally on well-drained sites, and greasewood (*Sarcobatus vermiculatus*) occurs on sites with alkaline soils and high water tables.

Vegetation that occurs from 1150 m on the alluvial fans to 1950 m is represented by a Mojave Desert community dominated by creosote bush and bursage. Joshua tree (*Yucca brevifolia*), single-needle pinyon pine (*Pinus monophylla*), and spiny menodora (*Menodora spinescens*) occur in a transition zone (1950–2100 m) that trends into a pinyon–Utah juniper (*Juniperus osteosperma*) woodland at ca 2100–2900 m. In the southern Inyo Mountains subalpine trees are found only on peaks above ca 2900 m. Limber pine (*Pinus flexilis*) is common in this region, with lesser amounts of bristlecone pine (*Pinus longaeva*), fernbush (*Chamaebatiaria millefollium*), and sagebrush. Several individuals of Sierra juniper (*Juniperus occidentalis* var. *australis*) also grow in the Inyo Mountains (Vasek 1966).

The nearest weather stations, Lone Pine (1120 m, 8 km west of the site) and Keeler (1100 m, 16 km southeast of the site), record an annual precipitation of 127 mm/yr and 80 mm/yr (Lee 1912, Elford 1970), respectively. Precipitation occurs primarily in the winter months with some rainfall in the summer months as isolated thunderstorms. Precipitation of 203–304 mm/yr has been estimated for the pinyon woodlands of the White Mountains at elevations of 1525–2135 m (St. Andre 1965).

METHODS

Three layers (A–C) were found in each of the two middens (HM1 and HM2) and were separated along stratigraphic planes. Once separated, the samples were disaggregated in distilled water in a covered bucket. This was done to prevent contamination by modern pollen. The disaggregated middens were sieved through a number 20-mesh (0.85-mm) screen with the decant saved for pollen analysis.

The midden debris was air-dried and hand-sorted under a dissecting microscope (7–40X magnification). Plant macrofossils were identified from reference materials. Interpretation of the macroremains is based on a relative abundance scale with 5 = >200 macroremains, 4 = 100–200, 3 = 30–99, 2 = 2–29, and a single specimen = 1 (Van Devender et al. 1987). Radiocarbon data were obtained primarily on fecal pellets (Table 1).

Processing for fossil pollen followed Faegri and Iverson (1989) and included the addition of *Lycopodium* tracer tables (Stockmarr 1971), acetolysis, staining, and suspension in silicon oil. A 300-grain count (range = 262–361; Table 3) of terrestrial pollen types was made at 400X magnification. The count excluded tracer, deteriorated, and aquatic pollen types. Pollen percentages were calculated based on the total terrestrial pollen counted in each sample. Many of the pollen types were identified to

TABLE 1. Radiocarbon analysis of the Owens Lake site (1155 m), Inyo County, California.

Sample	Radiocarbon years B.P.	Dated material	Lab number
HM2A	14,870 ± 130	Dung	Beta-39274
HM2C	16,010 ± 330	Dung	Beta-36732
HM2B	17,680 ± 150	Dung	Beta-35503
HM1A	20,590 ± 210	Debris	Beta-40000
HM1B	20,960 ± 240	Dung	Beta-34833
HM1C	22,900 ± 270	Dung	Beta-39273

family; however, some types were broken into morphological categories. *Pinus* pollen was separated into the haploxylon (white pine) and diploxylon (yellow pine) groups. *Ephedra* pollen was divided into *E. viridis* and *E. californica* pollen types. *Purshia-Cercocarpus* pollen types were discriminated from Rosaceae, and *Sarcobatus* was separated from other members of the Chenopodiaceae-*Amaranthus* (Cheno-am) group.

RESULTS

Macrofossils recovered from the middens document plants typically found in the pinyon-juniper zone of the Inyo Mountains. The exception to this is the occurrence of Rocky Mountain juniper (*Juniperus scopulorum*), which does not occur today in California. Fossil pollen recovered from the middens represents plants found within the midden as well as local species that either are avoided by packrats or occur beyond their foraging range (Anderson and Van Devender 1991).

Midden macrofossils are represented by the presence of Utah juniper in all samples (Table 2). Green ephedra (*Ephedra viridis*), wild rose (*Rosa woodsii*), *Menodora*, and pinyon pine occur in most of the other samples. Nevada greasebush (*Forsellesia nevadensis*) and Joshua tree also occur in several of the older middens (ca 22,900–20,590 yr BP). Rocky Mountain juniper is present in two middens dated to ca 17,680 and 16,010 yr BP.

Pollen identified from the middens generally supports macrofossil evidence (Table 3). Exceptions to this are the high amounts of *Artemisia* (ca 6–50%) and moderate amounts of Cheno-ams (ca 5.5–18%). High variability within pollen percentages may be due to the uncertain association with deposition time (months to centuries) and the year-to-year variability in pollen production.

DISCUSSION

During the Pleistocene several alpine glacier advances sculpted the Sierra Nevada, with at least three stages recorded during the late Wisconsin (Bursik and Gillespie 1993). The most recent episode, the Tioga advance, occurred during the full-glacial period, ca 21,000–18,000 yr BP. Significant advances in glacial chronology have been made in the last decade. Experimental analysis of the accumulation of cosmogenic Cl-36 suggests that maximum Tioga glaciation occurred prior to ca 21,000 yr BP (Phillips et al. 1990). Radiocarbon dates of 21,000 ± 130 yr BP (Lebetkin 1980) from tufa underlying an alluvial fan of inferred Tioga-age at Owens Lake (Fullerton 1986) and of 19,050 ± 210 yr BP on basal rock varnish from an outermost Tioga moraine in Pine Creek (Dorn et al. 1987) also support a maximum advance before this time. Timing on Sierra Nevada deglaciation is recorded by dates of glaciolacustrine sediments from mid-elevation west-side lakes (Swamp Lake ca 15,565 yr BP [1957 m; Batchelder 1980], Lake Moran ca 14,750 yr BP [2018 m; Edlund and Byrne 1991], Swamp Lake Yosemite ca 13,350 yr BP [1554 m; Smith and Anderson 1992]) and rock varnish dates on recessional Tioga moraines of ca 13,910 yr BP from Pine Creek (1830 m; Dorn et al. 1987). Dates from near the Sierran crest at Barrett Lake (2816 m) of ca 12,500 yr BP (Anderson 1990) and ca 10,300 yr BP in the Cottonwood Basin (ca 3000 m elevation; Mezger 1986) document high-elevation deglaciation on the east side.

The presence of ice in the Sierra Nevada had a significant impact on paleoenvironments within Owens Valley. The Owens River watershed covers ca 8500 km^2, with nearly all of its runoff originating in the 16% of this area lying in the eastern Sierra Nevada (Lee 1912, Smith and Street-Perrott 1983). Thus, as melting glaciers retreated, lakes within the valley would periodically fill, overflowing to a downstream lake in the chain. Based on glacial features, the glacial ice west of the Sierra Nevada crest increased the average elevation by ca 50 m in the south (Gillespie 1982, Mezger 1986) to as much as 300 m in the Yosemite National Park area (Alpha et al. 1987). Elevational increases east of the crest were insignificant because their glaciers were largely restricted to steep valleys. During the period of maximum ice extent within the Sierra Nevada, the increased average elevation of the range, caused by the combination of upwards of ca 600 m of ice plus the ca 100 m lowering of sea levels, may have had two effects on the Owens Valley and Inyo-White Mountains to the east. First, the higher average elevation of the Sierra Nevada intensified the rainshadow effect, as witnessed by the limited glaciation within the Inyo-White Mountains (Elliott-Fisk 1985, Swanson et al. 1993). Second, accumulation of

TABLE 2. Plant macrofossils identified from the Owens Lake site (1155 m), Inyo County, California. Relative abundance is based on >200 specimens = 5, 100–200 = 4, 30–99 = 3, 2–29 = 2, and a single specimen = 1.

Sample unit Sample age yr B.P.	HM2A 14,870	HM2C 16,010	HM2B 17,680	HM1A 20,590	HM1B 20,960	HM1C 22,900
TREES/SHRUBS						
Juniperus osteosperma	4	4	4	3	5	5
Juniperus scopulorum	—	3	2	—	—	—
Pinus monophylla	—	—	2	2	3	2
Ephedra viridis	2	—	2	5	5	5
Menodora spinescens	2	2	—	—	2	2
Mirabilis bigelovii	—	—	—	2	2	3
Eriogonum cf. *fasiculatum*	—	—	2	—	—	—
Forsellesia nevadensis	—	—	—	3	2	5
Artemisia tridentata	—	—	—	—	—	1
Chrysothamnus teretifolius	2	2	—	2	2	2
Ericameria cuneata	2	2	2	2	2	2
Tetradymia sp.	—	2	—	—	—	—
Atriplex polycarpa	—	—	—	—	1	—
Atriplex confertifolia	1	—	—	—	—	—
Grayia spinosa	—	1	—	—	—	—
Rosa woodii	2	2	2	—	—	2
Coleogyne ramosissima	—	—	—	—	1	—
Yucca cf. *brevifolia*	—	—	—	—	2	—
HERBS						
Sphaeralcea ambigua	2	—	—	—	2	2
Cirsium sp.	—	—	2	1	2	—
Boraginaceae	—	—	—	2	—	—
Amsinkia sp.	—	—	—	—	2	—
Cryptantha sp.	—	—	—	—	2	—
Plagybothrys spp.	—	—	—	—	—	2
Salvia sp.	—	—	—	—	1	—
Orthocarpus sp.	—	2	—	—	—	—
SUCCULENT						
Opuntia basilaris	1	—	2	2	4	4
GRASS						
Oryzopsis hymenoides	—	—	—	2	2	2

ice in the central Sierra Nevada probably deflected storm tracks further south than today and at a more frequent rate, as witnessed by wetter conditions in the modern Mojave Desert at that time (Spaulding and Graumlich 1986).

While the lake-level fluctuations at Owens Lake are poorly known, the periods of highstands and overflow can be estimated from the detailed records of pluvial Lake Russell and Searles Lake (Smith and Street-Perrott 1983, Benson et al. 1990). Owens Lake either received overflow from (Lake Russell) or contributed to (Searles Lake) pluvial lakes. Lake levels at Searles were generally high to overflowing between ca 25,000 and 10,000 yr BP. Between ca 21,000 and 15,000 yr BP a continuous highstand is inferred. Lake levels then returned to moderately low levels after ca 15,000 yr BP (Smith and Street-Perrott 1983) or ca 14,000 yr BP (Benson et al. 1990). For Lake Russell, lake-level chronologies suggest intermediate levels from at least 35,000 yr BP until a highstand after 15,000 (ca 14,000 or 13,000 yr BP; Benson et al. 1990).

During the full-glacial, the Owens Lake midden site was located in a transitional position between the full-glacial single-needle pinyon-juniper woodlands of the Mojave Desert and the Utah juniper–limber pine woodland of the southern Great Basin. In the rain shadow of the Sierra Nevada, the Eleana Range (1810 m) records limber pine and steppe shrubs (Spaulding 1990). North of the Owens Lake site at slightly higher elevations, colder conditions are recorded by the occurrence of Utah juniper and sparse limber pine at Eureka View (1430 m) at ca 14,700 yr BP (Spaulding 1990) and Utah juniper and Great Basin desert shrubs at the Volcanic Tablelands (Jennings and Elliott-Fisk 1993). Pinyon pine was not found in Death Valley where Utah juniper existed with a yucca semidesert (260–1280 m; Wells and Woodcock 1985). South of

TABLE 3. Percentages of identified pollen types from the Owens Lakes site (1155 m), Inyo County, California.

Sample unit	HM2A	HM2C	HM2B	HM1A	HM1B	HM1C
Sample age yr B.P.	14,870	16,010	17,680	20,590	20,960	22,900
Tracer	27.0	20.0	16.0	42.0	85.0	76.0
Deteriorated	5.0	30.0	10.0	15.0	13.0	3.0
Abies	0.0	0.3	0.0	0.0	0.3	0.0
Pinus haploxylon	9.4	9.7	3.0	9.2	30.4	9.0
Pinus diploxylon	12.2	1.7	1.5	1.5	0.9	9.0
Cupressaceae	13.6	23.4	32.5	22.5	36.6	34.7
Ephedra viridis-type	0.6	2.5	0.6	0.4	1.2	1.0
Ephedra californica-type	0.8	1.4	0.0	0.0	0.0	0.3
Menodora	0.0	0.3	0.0	0.0	0.3	0.0
Symphoricarpos	0.0	0.0	0.0	0.0	0.3	0.0
Quercus	0.0	0.0	0.0	0.0	0.3	0.0
Ambrosia	0.6	1.1	0.0	3.4	1.6	0.3
Artemisia	50.1	39.6	43.8	45.0	5.9	17.0
Cirsium	0.3	0.0	0.0	0.0	0.0	0.0
Other Compositae	1.1	1.7	1.8	5.3	7.1	6.4
Cheno-ams	5.5	10.6	6.4	7.6	9.6	18.0
Sarcobatus	4.7	5.6	8.8	4.6	2.8	4.2
Rosaceae	0.0	0.0	0.0	0.0	0.3	0.0
Purshia	0.0	0.0	0.0	0.0	0.9	0.0
Ceanothus	0.0	0.0	0.0	0.0	0.3	0.0
Eriogonum	0.3	0.6	0.3	0.0	0.0	0.0
Solanaceae	0.0	0.0	0.9	0.0	0.0	0.0
Cruciferae	0.0	1.1	0.0	0.0	0.3	0.0
Leguminosae	0.6	0.0	0.0	0.4	0.6	0.0
Polemonaceae	0.0	0.0	0.3	0.0	0.0	0.0
Gramineae	0.3	0.6	0.0	0.0	0.0	0.0
Terrestrial total	361	359	329	262	322	311
AQUATICS						
Typha	0.0	0.0	0.0	0.0	1.0	0.0

the Owens Lake site, the Mojave Desert full-glacial vegetation records the widespread occurrence of a pinyon-juniper woodland (Spaulding 1990).

Records from the Owens Lake site (1155 m) and Skeleton Hills (925 m; Spaulding 1990) are the only documentation of pinyon pine during the full-glacial at this latitude. The lower limit of pinyon pine is recorded in the Skeleton Hills at 925 m. In Owens Valley the upper limit of pinyon is constrained between 1155 m (this report) and 50 km north in the Volcanic Tablelands at 1340 m (Jennings and Elliott-Fisk 1993). Despite the absence of pinyon at Death Valley, these sites define the northern distribution of pinyon in the Mojave Desert during the full-glacial.

The most interesting macrofossil found in the midden series dating 17,680 and 16,010 yr BP is Rocky Mountain juniper. This tree is not found in California today but occurs in the Charleston Mountain area of southwestern Nevada, ca 225 km east of the site. The elevational and latitudinal migration of Rocky Mountain juniper is well understood in the southeastern and central Great Basin (Thompson 1990). Using terpene variations, Adams (1983) provided evidence for Rocky Mountain juniper colonization in post-glacial environments within the extreme northern and southern extensions of its range, suggesting migration routes along pluvial lake corridors. Rocky Mountain juniper is generally restricted to regions that lack pronounced summer droughts (West et al. 1978, Thompson 1988). In the southern part of its range, Rocky Mountain juniper is restricted to riparian settings or areas of shallow groundwater and springs (Adams 1983). This information is germane to the history of lake-level fluctuations within the Owens Valley area.

The occurrence of Rocky Mountain juniper at the Owens Lake site is thus partially explained by local climatic factors associated with pluvial lake highstands. Its existence around Owens Lake between ca 17,680 and 16,010 yr BP was probably influenced by relatively high water tables or locally humid conditions associated with the highstand at that time. Its subsequent absence by 14,870 yr BP was probably a result of declining lake levels.

CONCLUSIONS

The Owens Lake midden site provides evidence for paleoenvironmental change along the shore of Owens Lake spanning the full-glacial Tioga advance. The midden sequence from ca 23,000 to 17,680 yr BP records a juniper-pinyon woodland with associated xeric upland desert scrub and possible Joshua tree. The presence of Rocky Mountain juniper at 17,680 and 16,010 yr BP suggests a mesophytic association due to the presence of Owens Lake. In apparent contradiction, drier conditions are recorded after ca 17,500 yr BP at nearby locations (Death Valley, Wells and Woodcock 1985; Skeleton Hills, Spaulding 1990; Sheep Range, Spaulding 1981), and this is supported at the Owens Lake site as pinyon pine is not recorded after 17,680 yr BP.

Dated moraines record the timing of the Tioga glaciation (Dorn et al. 1987, Bursik and Gillespie 1993). Prior to ca 19,000 yr BP, pluvial lake highstands are not recorded (Bursik and Gillespie 1993), as some available moisture was sequestered to the Owens Lake chain in the alpine ice of the Sierra Nevada. A deglaciation with possible readvances, between ca 19,000 and 13,000 yr BP, caused the lakes of the Owens River to achieve highstands. The close proximity of the Owens Lake highstand allowed sufficient effective moisture for Rocky Mountain juniper to exist close to the midden site (within 10 m elevation and <100 m distance from the lake).

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